*भारतीय मानक*

# स्वस्थाने भेथता परीक्षण

**भाग 1 ओवरबर्डन में परीक्षण — रीति संहिता**

*( दूसरा पुनरीक्षण )*

*Indian Standard*

# *IN-SITU* PERMEABILITY TESTS

**PART 1 TESTS IN OVERBURDEN — CODE OF PRACTICE**

*( Second Revision )*

ICS 93.020



B U R E A U O F I N D I A N S T A N D A R D S
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Geological Investigations and Subsurface Exploration Sectional Committee, WRD 5

## FOREWORD

This Code (Part 1) (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Geological Investigations and Subsurface Exploration Sectional Committee had been approved by the Water Resources Division Council.

This Code was first published in 1969 and revised in 1985. The present revision is proposed to reflect the experience gained on the subject since then.

Field permeability of subsurface strata is necessary in connection with various engineering problems, such as design of cut-off for earth dam, calculation of pumping capacity for dewatering excavations and determination of aquifer constants of subsurface strata.

The field permeability tests are carried out to determine permeability of each subsurface strata encountered up to bed rock as well as to ascertain overall permeability of strata. The tests are carried out in standard drill holes where subsurface explorations for foundations are carried out by drilling. The tests are also carried out in auger holes or bore holes of larger size than those made by standard drill rods. These tests are convenient and reliable for depth up to 30 m and they dispense with costly drilling operations. The tests carried out are either pumping in or pumping out type. When the stratum being tested is above water table, the pumping in test is carried out and when it is below water table then either pumping in or pumping out test may be conducted.

The coefficient of permeability is usually evaluated on the basis of Darcy's law which states that the rate of flow through a porous medium is proportional to the hydraulic gradient. This relationship is applicable for steady and laminar flow through saturated soils. A reliable determination of permeability may be made only when the above conditions for the validity of Darcy's law are fulfilled. Further, the reliability of the values of permeability depends upon the homogeneity of the strata tested and on the validity of the following assumptions in the formula used:

a) Non-pumping piezometer surface is horizontal; and
b) Non-pumping aquifer is horizontal, of uniform saturated thickness, of infinite aerial extent and is homogeneous.

This Code is published in two parts. Other part in the series is:

Part 2 Test in bedrock

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

*Indian Standard*

# *IN-SITU* PERMEABILITY TESTS

## PART 1 TESTS IN OVERBURDEN — CODE OF PRACTICE

*( Second Revision )*

### 1 SCOPE

**1.1** This Code (Part 1) specifies the methods, as mentioned in **1.2** and **1.3** out of a number of methods, of determining field permeability in overburden. These are more commonly adopted for civil engineering purposes.

**1.2 Pumping in Tests (Gravity Feed in Drill Holes or Bore Holes)**

a) Constant head method (cased well, open end test);
b) Falling head method (uncased well); and
c) Slug method.

**1.3 Pumping Out Tests**

a) Unsteady state;
b) Steady state; and
c) Bailor method.

### 2 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply.

**2.1 Coefficient of Permeability** — The rate of flow of water under laminar flow conditions through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and at a standard temperature of 27°C.

**2.1.1** As it is not possible to control the temperature in the field to 27°C, the coefficient of permeability $K_{27}$, at 27°C is calculated by the following formula:

$$K_{27} = \frac{\eta_t K_t}{\eta_{27}}$$

where

$\eta_t$ = viscosity of water at the field temperature, $t$;
$K_t$ = coefficient of permeability at the field temperature, $t$; and
$\eta_{27}$ = viscosity of water at 27°C.

**2.2 Coefficient of Storages** — It is defined as the volume of water that a unit decline in head releases from storage in a vertical column of the aquifer of unit cross-sectional area and is given by the following formula:

$$S = n\, b\, \gamma_w \left( \frac{\beta + \alpha}{\eta} \right)$$

where

$\eta$ = porosity of sand;
$\gamma_w$ = unit weight of water;
$b$ = aquifer thickness;
$\beta$ = compressibility of water or reciprocal of its bulk modulus of elasticity; and
$\alpha$ = vertical compressibility of the solid skeleton of the aquifer.

**2.3 Coefficient of Transmissivity (*T*)** — It is defined as the rate of flow of water through a vertical strip of aquifer of unit width under a unit hydraulic gradient. It characterizes the ability of the aquifer to transmit water and is given by the following formula:

$$T = Kb$$

where

$K$ = coefficient of permeability; and
$b$ = aquifer thickness.

**2.4 Constant Head Method** — The method in which the water level in the test hole is maintained constant and the permeability is computed from the data of steady state constant discharge.

**2.5 Falling Head Method** — The method in which the water level in the test hole is allowed to fall and the equivalent permeability is computed from the data of the rate of fall of the water level.

**2.6 Slug Method** — The test done by instantaneous injection of a given quantity of 'slug' of water into a well, and determining the coefficient of permeability from the fall of water level.

**2.7 Bailor Method** — The test done by instantaneous bailing of water from a well and determining the coefficient of permeability from the data of the recovery of water level.

## 3 PUMPING IN TEST

### 3.1 Applicability

**3.1.1** The pumping in test is applicable for strata in both cases of above and below water table. The test is especially performed in formations of limited thickness. The tests give permeability of the material in the immediate vicinity of the bottom of the drill hole. It may thus be used for determining the permeability of different layers in stratified foundations and thus check the effectiveness of grouting in such formulations. This method is economical and do not require elaborate arrangements required for the pump out tests.

**3.1.2** *Limitations*

**3.1.2.1** In the pumping in test method water is fed from outside and, therefore, the test results are likely to be affected by the thin film formed by the sedimentation of suspended fines present in the water.

**3.1.2.2** The method does not provide the overall permeability of the strata but the permeability of a stratum of thickness five times the diameter of the hole below and above the level of casing.

### 3.2 Constant Head Method (Cased Well-Open End Test)

**3.2.1** The constant head method is used when the permeability of the strata being tested is high.

**3.2.2** *Equipment*

**3.2.2.1** *Drilling or boring set or auger*, required for excavating a bore hole.

**3.2.2.2** *Driving pipe casing or blind pipe*, of length equal to the depth up to which testing is to be done.

**3.2.2.3** *Pumped water supply or a number of drums of 200 litre capacity full of water*

The number of drums depends upon the expected water percolation. One drum should have a regulating valve at the bottom and an overflow in the form of sharp crest at the top.

**3.2.2.4** *Delivery hose pipe or rubber tubing*, of 12 mm diameter fitted with a regulating cock.

**3.2.2.5** Arrangements for measuring water level in the test holes like a mason's plumb with a measuring tape of preferably an electric probe as described in **3.2.2.6**.

**3.2.2.6** The electric probe (*see* Fig. 1) consists of a long wire kept straight by means of a weight tied at the bottom end. This probe should be connected to a cell and galvanometer. A connecting wire passes from the other terminal of the galvanometer to earth. It may be tied to the metal casing of the observation well itself. Then galvanometer needle will show deflection on completion of the electric circuit when the probe touches water in the hole. The depth of the electric wire lowered is measured by tape or by the graduations

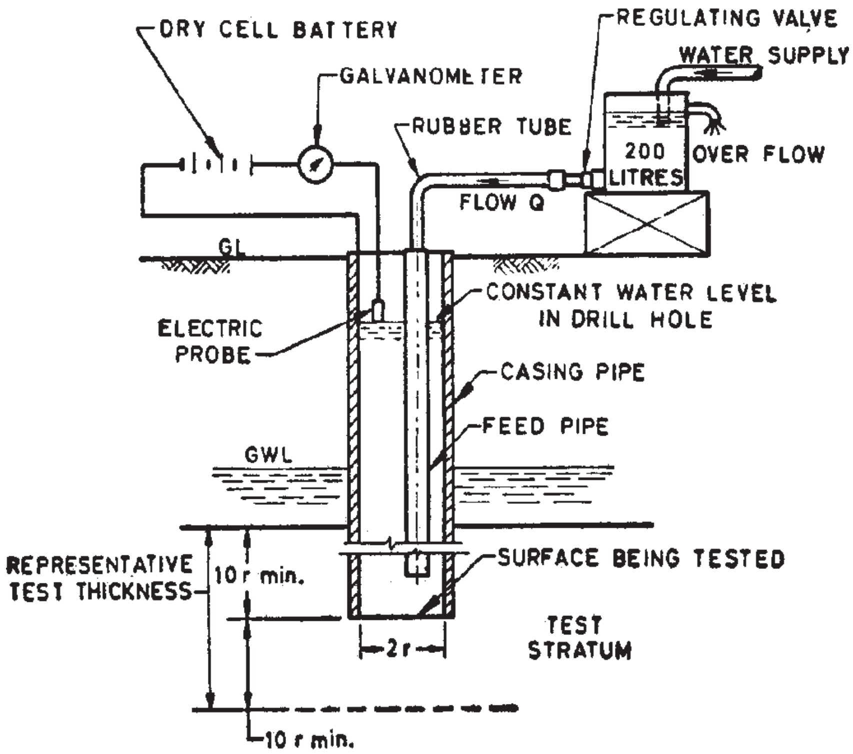



FIG. 1 SET-UP FOR CONSTANT HEAD METHOD (GRAVITY FEED, OPEN-END TYPE)

marked on the electric wire itself for determining the depth of water level in the hole.

**3.2.2.7** *Miscellaneous equipment*, stop watches, graduated cylinders pressure gauges, water meter and enamelled bucket for measuring discharge.

**3.2.3** *Procedure*

**3.2.3.1** In this method, a hole should be drilled or bored up to the level at which the test is to be performed. The casing should be sunk by drilling and driving or jetting with water and driving, whichever gives the tightest fit to the casing in the hole. The casing should be simultaneously driven as the drilling or boring of the hole is in progress. After the required level is reached, the hole should be cleaned by means of scooping spoons and bailor. If the hole extends below ground water level, the hole should be kept full of water while cleaning it (as otherwise, due to water pressure, soil may squeeze into the bottom of the casing pipe) and should be cleaned by passing air under pressure by air jetting method.

**3.2.3.2** After the hole is cleaned the test should be started by allowing clean water through a metering system to maintain gravity flow at constant head. The flow should be adjusted by the regulating valve in such a way so as to obtain steady water level in the hole. In the tests above water table, a stable constant level is rarely obtained, and a surging of the level within 20 mm to 30 mm at a constant rate of flow for about 5 min may be considered satisfactory.

**3.2.3.3** For measuring water level or constant water level maintained in the hole during test, the naked point of the enamelled wire of the electric probe should be lowered in the hole till it touches the water level. The observations of the water level at 5 min intervals should be noted. When three consecutive readings show constant values, further observations may be stopped and the constant reading should be taken to the depth of water level. Alternatively, the water reading may also be taken by means of soundings by mason's plumb.

**3.2.4** *Observations*

The observations of the test should be recorded suitably. A recommended proforma for the record of results is given in Annex A.

**3.2.5** *Computations of Coefficient of Permeability*

**3.2.5.1** The permeability by constant head method (open-end test) should be obtained from the following relation determined by electrical analogy experiments:

$$K = \frac{Q}{5.5\,rH} \qquad \dots (1)$$

where

$K$ = coefficient of permeability;

$Q$ = constant rate of flow into the hole;

$r$ = internal radius of casing; and

$H$ = differential head of water = $H_1$ (gravity head) – $H_f$ (head loss due to friction).

NOTES

**1** The value of $H$, for gravity test made below water table is the difference between the level of water in the casing and the ground water level. For test above water table, $H_1$ is the depth of water in the hole as shown in Fig. 2.

**2** The value of $H_f$ (head loss due to friction) may be obtained from Fig. 3 and Fig. 4 for EX, AX, BX and NX size rods.

**3.2.5.2** When $K$ is measured, in cm/s, $Q$, in litre/min, and $H$, in m, equation (1) may be written as:

$$K = C_1 \times Q/H$$

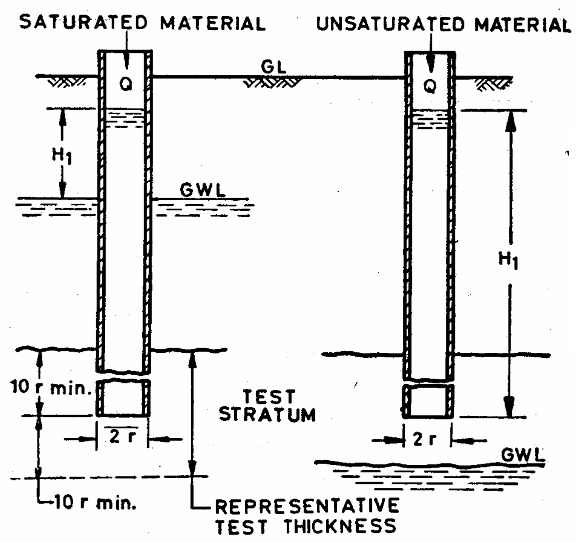
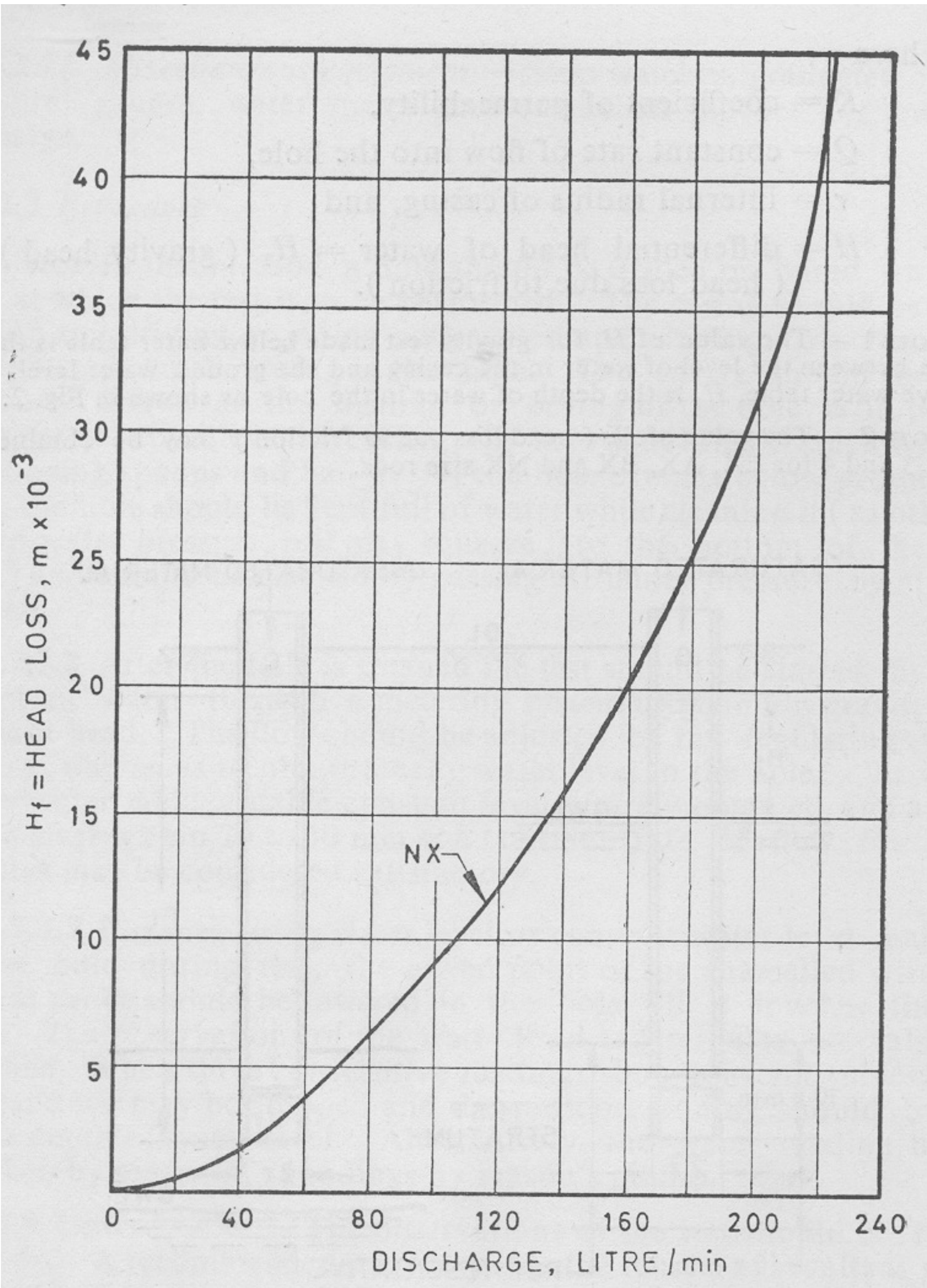



FIG. 2 CONSTANT HEAD METHOD — PUMPING IN TYPE (GRAVITY FEED, OPEN-END TEST)




**FORMULA USED**

$$H_f = \frac{fl}{d} \times \frac{[Q/(\pi d^2/4)]^2}{2g}$$

where

$H_f$ = head loss

$f$ = friction constant

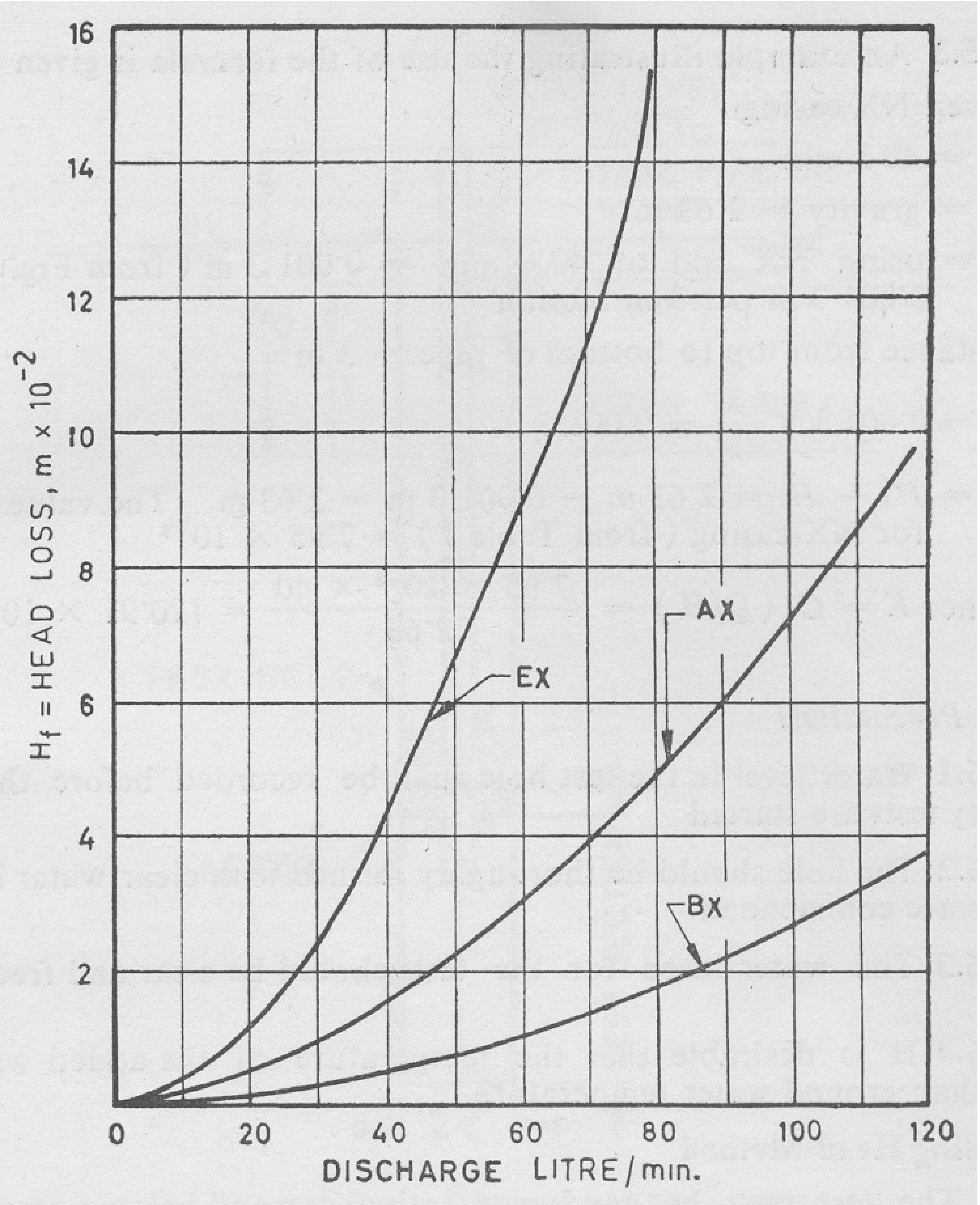
$d$ = inside diameter of rod

$Q$ = discharge

$l$ = length of rod

$g$ = acceleration due to gravity

FIG. 3 HEAD LOSS DUE TO PIPE FRICTION FOR NX SIZE RODS PER 3 m LENGTH OF DRILL ROD *VERSUS* DISCHARGE




**FORMULA USED**

$$H_f = \frac{fl}{d} \times \frac{[Q/(\pi d^2/4)]^2}{2g}$$

where

| | |
|---|---|
| $H_f$ = head loss | $d$ = inside diameter of rod |
| $l$ = length of rod | $Q$ = discharge |
| $f$ = friction constant | $g$ = acceleration due to gravity |

FIG. 4 HEAD LOSS DUE TO PIPE FRICTION FOR EX, AX AND BX SIZE RODS PER 3 m LENGTH OF DRILL ROD *VERSUS* DISCHARGE

Values of $C_1$, which vary with the size of casing and rods, are given in Table 1.

**3.2.5.3** An example illustrating the use of the formula is given below:

Given NX casing

$Q$ = 40 1/min

$H_1$ = gravity = 2.63 m

$H_f$ = using NX rod at 40 1/min = 0.001 3 m (from Fig. 3) = 0.001 3 m per 3 m section

Distance from top to bottom of pipe = 3 m

$$H_f = 0.001\,3 \times \frac{3}{3} = 0.001\,3 \text{ m}$$

$H$ = $H_1 - H_f$ = 2.63 m – 0.001 3 m = 2.63 m. The value of $C_1$ for NX casing (from Table 1) = $7.95 \times 10^{-3}$

Hence

$$K = C_1\,(Q/H) = \frac{7.95 \times 10^{-3} \times 40}{2.63} = 120.91 \times 10^{-3} \text{ cm/s}$$

**3.2.6** *Precautions*

**3.2.6.1** Water level in the test hole shall be recorded before the permeability tests are started.

**3.2.6.2** The hole should be thoroughly flushed with clear water before the tests are commended.

**3.2.6.3** The water used for the tests should be clear and free from silt.

**3.2.6.4** It is desirable that the temperature of the added water is higher than ground water temperature.

**3.3 Falling Head Method**

**3.3.1** The test may be conducted both above and below water table but is considered more accurate below water table. It is applicable for strata in which the hole below the casing pipe can stand and has low permeability; otherwise the rate of fall of the head may be so high that it may be difficult to measure.

**3.3.2** *Equipment*

**3.3.2.1** All the equipment listed in **3.2.2**.

**3.3.2.2** Pneumatic mechanical or any other suitable type packers of the diameter of the hole and length when expanded shall be equal to five times the diameter of the hole.

**3.3.2.3** A perforated pipe of suitable length. The test set up is shown in Fig. 5.

**3.3.3** *Procedure*

The hole should be drilled or bored up to the bottom of the test horizon and cleaned by the method described in **3.2.3.1**. After cleaning the hole, the packer should be fixed at the desired depth so as to enable the testing of the full section of the hole below the packer. In conducting packer tests standard drill rods should be used. The water pipe should be filled with water up to its top and the rate of fall of the water inside the pipe

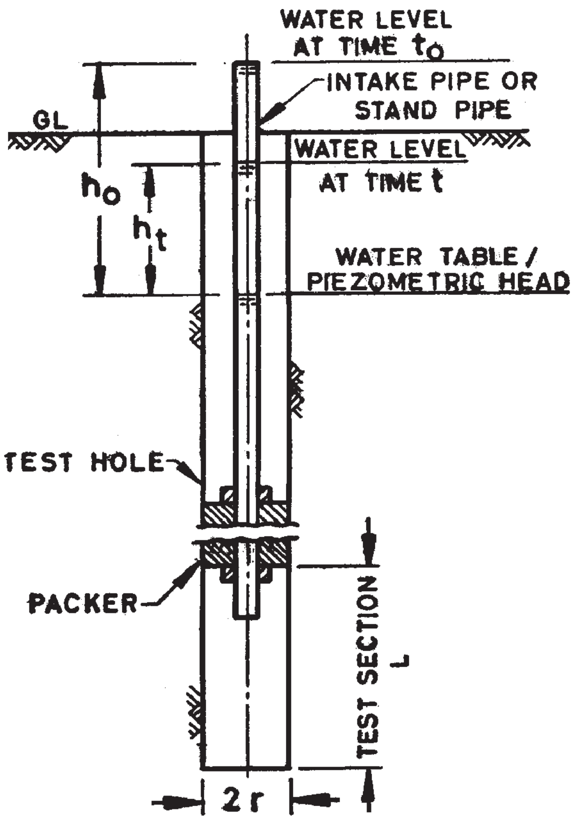



FIG. 5 SET-UP FOR FALLING HEAD METHOD

**Table 1 Values of $C_1$ ($\times 10^{-3}$)**
(*Clause* 3.2.5.2)

| Sl No. | | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|---|
| i) | Size of casing | EX | AX | BX | NX | | | |
| ii) | Diameter of hole (2$r$), in mm | 38.1 | 48.4 | 60.3 | 76.2 | 100 | 150 | 200 |
| iii) | $C_1$ ($\times 10^{-3}$) | 15.90 | 12.50 | 10.0 | 7.95 | 6.06 | 4.04 | 3.03 |

should be recorded. If the hole cannot stand as such then casing pipe with perforated section in the strata to be tested should be used.

**3.3.4** *Observations*

The observations of the test should be recorded suitably. A recorded proforma for the record of results is given in Annex B.

**3.3.5** *Computations of Coefficient of Permeability*

**3.3.5.1** The permeability by falling head method in an uncased hole should be computed by the following relations:

$$K = \frac{d^2}{8L}(\log_e \frac{L}{R})\frac{\log_e h_1/h_2}{t_2 - t_1} \qquad \text{.... (2)}$$

where

$K$ = coefficient of permeability;

$d$ = diameter of intake pipe (stand pipe);

$L$ = length of test zone;

$h_1$ = head of water in the stand pipe at time $t_1$, above piezometeric surface;

$h_2$ = head of water in the stand pipe at the time $t_2$, above piezometeric surface; and

$R$ = radius of hole.

**3.3.5.2** The formula is based on the following assumptions:

a) The soil stratum is homogeneous and the permeability of soil is equal in all directions; and
b) The soil stratum in which the intake point is placed is of infinite thickness and that artesian conditions does not prevail.

**3.3.5.3** The head ratio $h_t/h_0$ (where $h_t$ = head of water in the stand pipe at any time $t$ and $h_0$ = depth of static water level at time $t_0$) *versus* time curve should be plotted on the semilog plot as shown in Fig. 6. The curve shows pronounced initial curvature whereas after a time lag of about 20 min, the curve is straight. A straight line through the origin and parallel to the straight portion of the curve should be drawn to represent a steady state of flow into the test strata. The value of $h_1/h_0$ and $h_2/h_0$ corresponding to time $t_1$, and $t_2$ respectively is read from the graph. The value $h_1/h_2$ corresponding to time $t_1$ and $t_2$ is calculated and substituted in equation (2) to obtain the coefficient of permeability.

**3.3.5.4** A numerical example illustrating the use of the formula is given below:

$L$ = 762 cm $\qquad d^2 = (1.9)^2 = 3.61$ cm$^2$

$d$ = 1.9 cm $\qquad L/R = 762/3.81 = 200$

$R$ = 3.81 cm $\qquad \log_e(L/R) = \log_e 200 = 5.30$

$h_0$ = 57.2 cm

$h_1/h_0$ = 0.4 $\qquad t_1 = 19.0$ min (from Fig. 6)

$h_2/h_0$ = 0.2 $\qquad t_2 = 33.50$ min (from Fig. 6)

$$\frac{h_1/h_0}{h_2/h_0} = \frac{0.4}{0.2}$$

or $h_1/h_2 = 2$

Substituting the value in equation (2)

$$= \frac{3.61}{8 \times 762} \times 5.3 \frac{\log_e .2}{14.5} \text{cm/min}$$

$$= 2.17 \times 10^{-4} \times \frac{1}{60} \times 0.693 \text{ cm/s}$$

$= 2.48 \times 10^{-6}$ cm/s under unit hydraulic gradient.

## 3.4 Slug Method

**3.4.1** The test is conducted in artesian aquifers of small to moderate transmissivity ($T < 6 \times 10^5$ l/day/m) and gives representative values for water bearing material close to the well. It affords a quick method for approximately determining the overall permeability in the close vicinity of the well.

**3.4.2** *Limitations*

**3.4.2.1** The method gives transmissivity of material in the immediate neighbourhood of the well.

**3.4.2.2** Serious errors shall be introduced unless the well is fully developed and completely penetrates the aquifer.

**3.4.3** *Equipment*

**3.4.3.1** All the equipment listed in **3.2.2**.

**3.4.3.2** An appliance for instantaneous injection of water in the hole, comprising a 200 litre drum having an opening with nipple at the bottom and a cover of flange with gasket connected to a rope placed over the opening as shown in Fig. 7.

**3.4.3.3** *Blocks*

Fifteen centimetre high to be placed below the container (*see* **3.4.3.2**) to provide a vent for the escape of air above the water surface in the well.

**3.4.4** *Procedure*

**3.4.4.1** In this method also, the drilling or boring of the hole up to the bottom of the test horizon, sinking the casing and cleaning the hole should be done by the method described in **3.2.3.1**.

**3.4.4.2** After cleaning the hole, water level

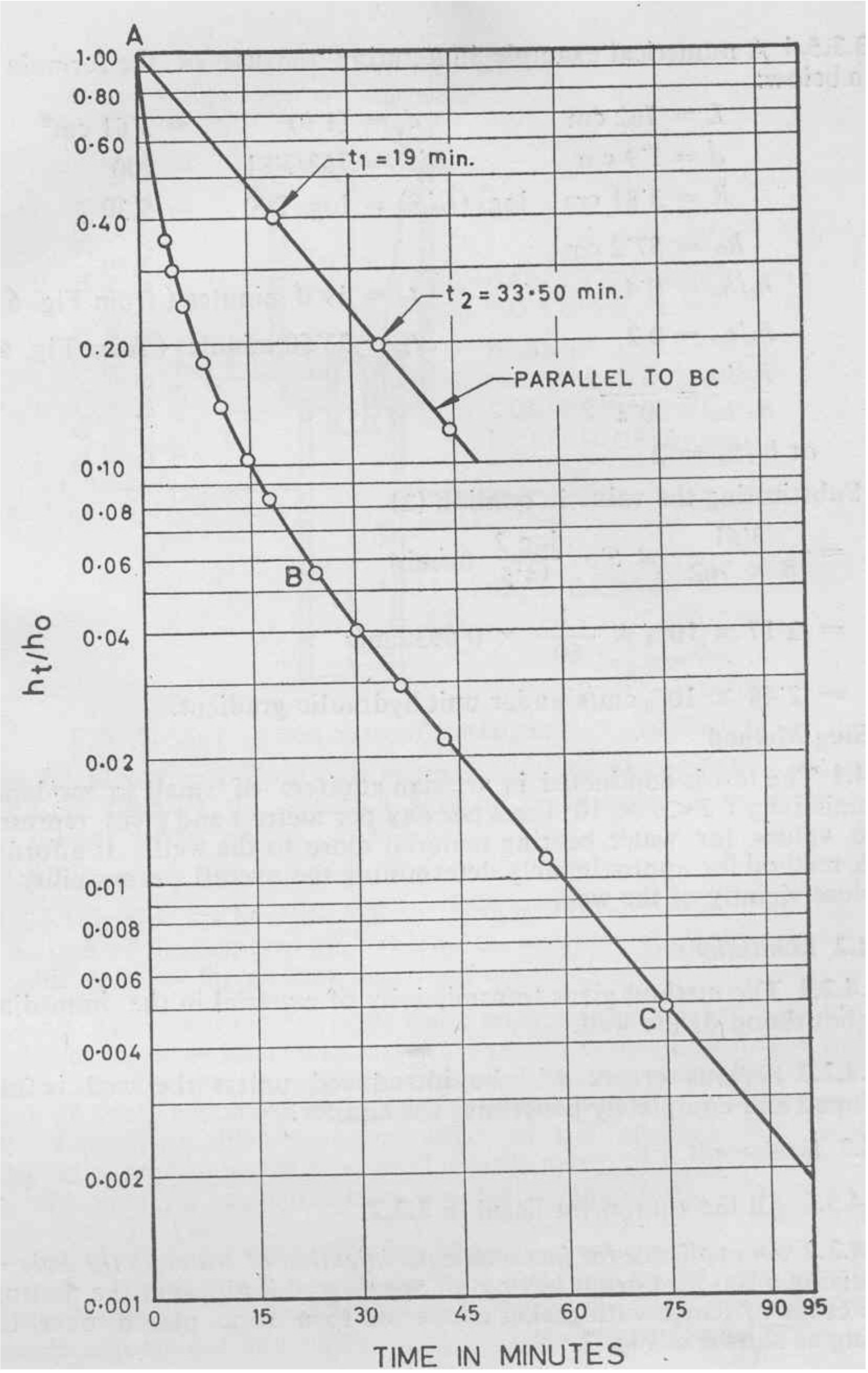



FIG. 6 SEMI-LOG PLOT OF HEAD RATIO *VERSUS* TIME OF TEST (FALLING HEAD METHOD)

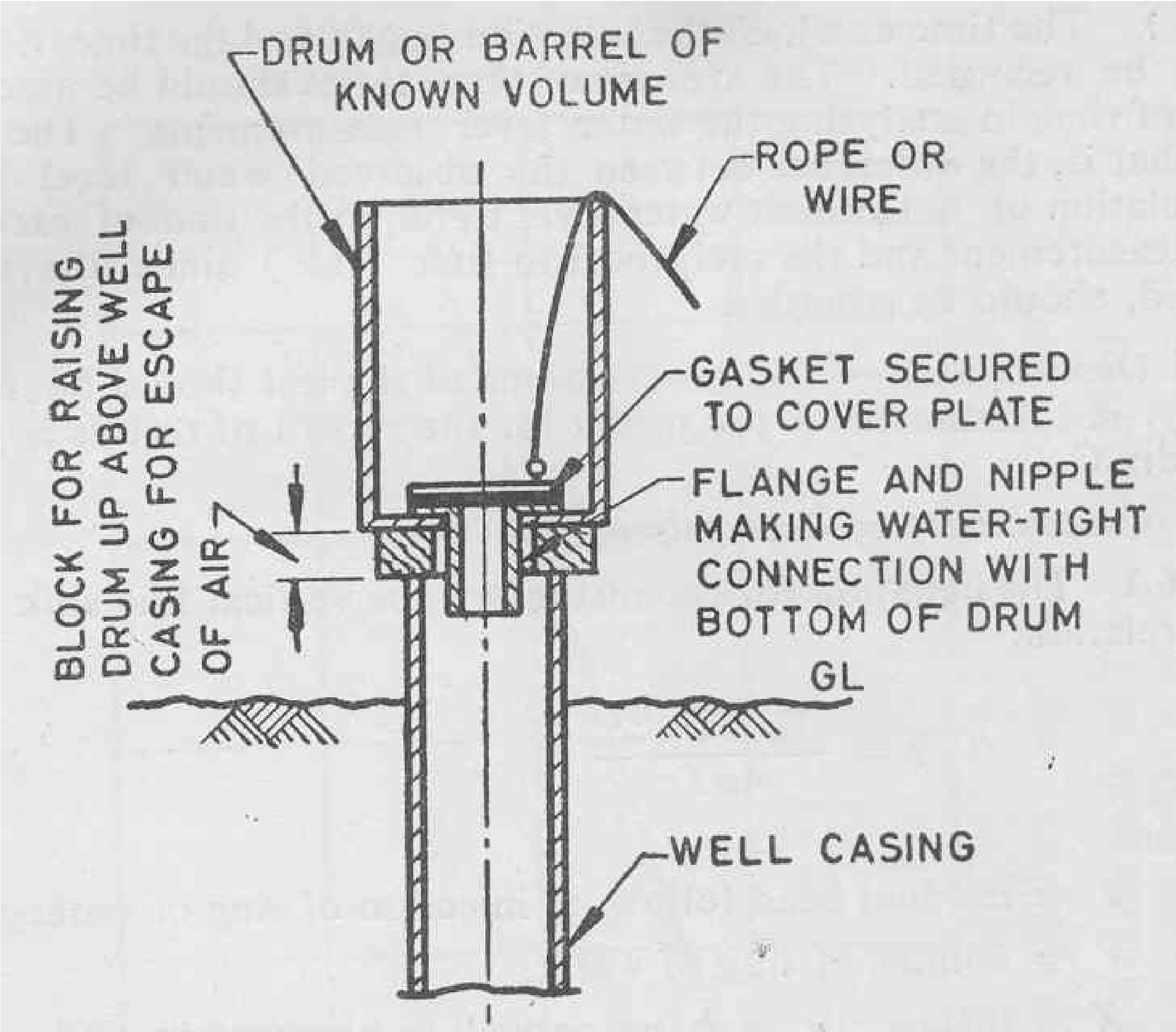



FIG. 7 SET-UP FOR SLUG TEST (PUMPING-IN TYPE)

measurements should be recorded at frequent intervals for a short period before injection of a slug of water into the well, to define the trend of existing water level (the volume of water which can be injected into a well as a slug is ordinarily small. Largely for this reason the effect of the injected slug is not usually measurable in the aquifer at points removed from the injection well. Water level measurements are made, therefore, only in the injection well). The container is then placed suitably on blocks and a known volume $V$ of water is injected almost instantaneously into the well by quickly opening the flange by the rope attached to it. The injection apparatus should be removed quickly from the well and water level measurements should be resumed with the help of an electric probe (*see* **3.2.3.3**). The time at which the injection began and the time it stopped should be recorded. The average of these times should be used as the origin of time in analyzing the water level measurements. The residual head, that is, the difference between the observed water level and the extrapolation of antecedent water level trend, at the time of each water level measurement and the reciprocal to time ($1/t$) since the injection occurred, should be recorded.

**3.4.5** *Observations*

The observations of the test should be recorded suitably. A recommended proforma for the record of results is given in Annex C.

**3.4.6** *Computation of Transmissivity*

**3.4.6.1** The equation for the instantaneous vertical line sink is given by the relation:

$$s = \frac{V_e^{-x^2S/4Tt}}{4\pi Tt} \qquad \text{... (3)}$$

where

$s$ = residual head following injection of slug of water;

$V$ = volume of slug of water;

$X$ = distance from injection well to observation well;

$S$ = coefficient of storage;

$T$ = coefficient of transmissivity; and

$t$ = time since slug was injected.

**3.4.6.2** For water level measurements in the injection hole, $x$ is replaced by the effective radius of the well $r_w$. For values of $x$ as small as $r_w$ specially where $S$ is small, as for artesian aquifers, the exponent of $e$ in equation (3), approaches zero as $t$ becomes large and the value of the exponential term approaches unity. Then if $V$ is expressed in litre, $T$ in litre per day per metre, $t$ in min and $s$ in m, equation (3) may be written in the form:

$$T = \frac{114.6\ (V.1/t_m)}{s} \qquad \ldots (4)$$

where

$t_m$ = time following instantaneous injection of slug of water.

**3.4.6.3** The residual head ($s$) in metre should be plotted against the reciprocal of the time, in minute since the injection occurred ($1/t_m$) as shown in Fig. 8. A straight line drawn through the observed data should pass through the origin (if the observed data from a slug test do not fall on the straight line the observation well may be sluggish and, if so, should be further developed). An arbitrary point is picked on the straight line and the corresponding values of $1/t_m$ and $s$ should be substituted in equation (4).

**3.4.6.4** An example illustrating the use of equation (4) is given below:

$1/t_m$ = 0.5 (*see* Fig. 8)

$s$ = 0.05 (*see* Fig. 8)

$V$ = 150 litre

$$T = 114.6\ (v.1/t_m) = \frac{114.6 \times 150 \times 0.5}{0.05}$$

$$= 171\ 900 \text{ litre/day/m}$$

## 4 PUMPING OUT TESTS

### 4.1 Applicability

The pumping out test is an accurate method for finding out *in-situ* permeability of the strata below water table or below river bed. This method is best suited for all ground water problems where accurate values of permeability representative of the entire aquifer are required for designing cut off or planning excavations.

### 4.2 *Equipment*

**4.2.1** All the equipment listed in **3.2.2**.

**4.2.2** *Water Meter*, one impeller type water meter; should be able to read up to 0.01 litre, to be tested once in a month.

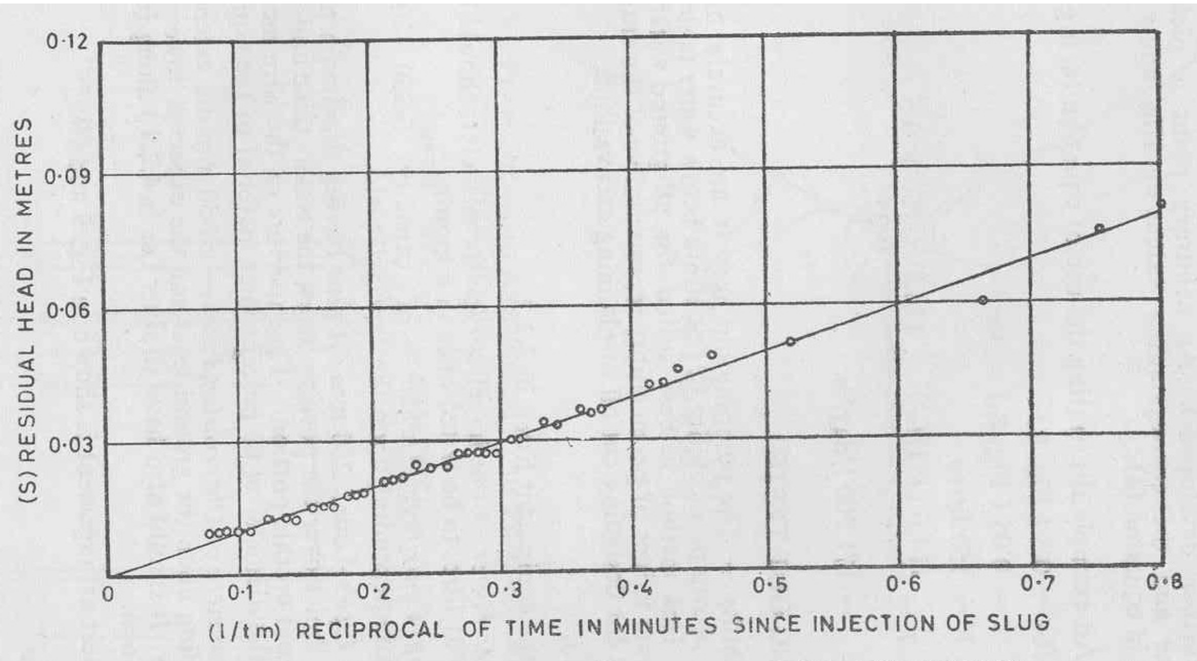



FIG. 8 RESIDUAL HEAD *VERSUS* RECIPROCAL OF TIME FOLLOWING THE INSTANTANEOUS OF SLUG OF WATER

**4.2.3** *Pump Centrifugal/Turbine,* of capacity 5 l/min to 250 l/min and 250 l/min to 1 600 l/min depending upon the expected yield.

**4.2.4** *Well Pipe*, one, 250 mm GI pipe having maximum number of 25 mm dia holes over the portion below the water table and having a wire mesh fixed on this portion. The aperture of the wire mesh should be taken as the diameter of 60 percent finer material of the aquifer.

**4.2.5** *Piezometers or Observation Pipes*, of 50 mm dia extending to a depth depending upon the ground level and the expected lowering of the ground water. It should also have strainer (as in **4.2.4**) along full length except top 0.6 m.

**4.2.6** The test arrangement is shown in Fig. 9 and Fig. 10.

**4.3 Procedure**

**4.3.1** The installation for pumping out test consists of fully or partially penetrating well and suitable number of piezometers arranged on 3 tiers preferably 120° to each other. A 400 mm bore hole should be drilled by using direct or reverse circulation methods of drilling (based on prevailing geohydrological conditions) extending to the bottom of the test section. Where the total saturated thickness of the aquifer is very large and drilling the hole to bottom of the aquifer is expensive, partially penetrating well may be used. The impervious boundary or bed rock should be ascertained by drilling. Adjustment for partial penetration should be made by Kozeny's relation given in **4.3.5**.

**4.3.2** The well consists of 250 mm dia GI pipe having maximum number of holes over the portion below the water table and having wire mesh fixed around this portion of the pipe. The aperture of the wire mesh shall depend upon the grading of the surrounding aquifer and should be taken as the diameter of 60 percent finer material. A conical shoe at the bottom and a blind pipe on the top, from water table to ground surface are provided. A 75 mm thick coarse sand and travel filter should be placed all round the screen to a height approximately 3 m above the top of the screen. During development of the well, there is a possibility of more intake of coarse sand due to large quantities of finer sands being pumped out. The shrouding should be continued till the well yields sand free water.

**4.3.3** For carrying out the test, the well should be first pumped up to the depth for which the overall permeability is to be determined. The pump should be run at a constant rate of discharge continuously till the pumped well attains equilibrium conditions in the piezometer surface. This period varies from 10 h to 100 h depending upon the aquifer conditions, its thickness, permeability and slope. The observation in piezometers should be taken at suitable intervals of time. In the initial stages, say for the first 15 min, the observations may be taken at 30 s interval; for the next 30 min at 1 min interval; for the next 30 min at 2 min interval and for the next 2 h at 5 min interval. After this it may be increased to hourly and then to 5 hourly and 10 hourly intervals till equilibrium conditions are achieved. These intervals are only arbitrary and may be changed to suit the site conditions. After completion

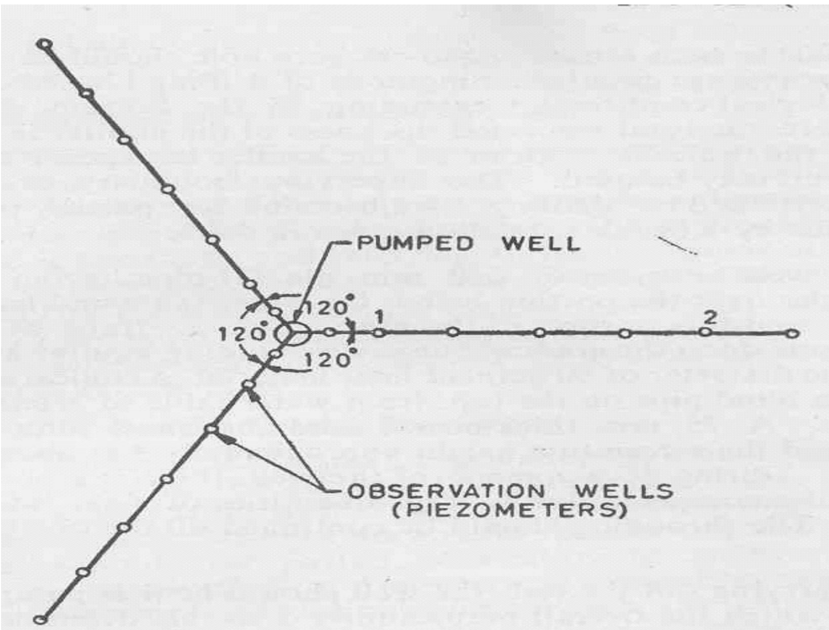



FIG. 9 PLAN SHOW ARRANGEMENT OF PUMPING WELL AND PIEZOMETERS FOR PUMPING

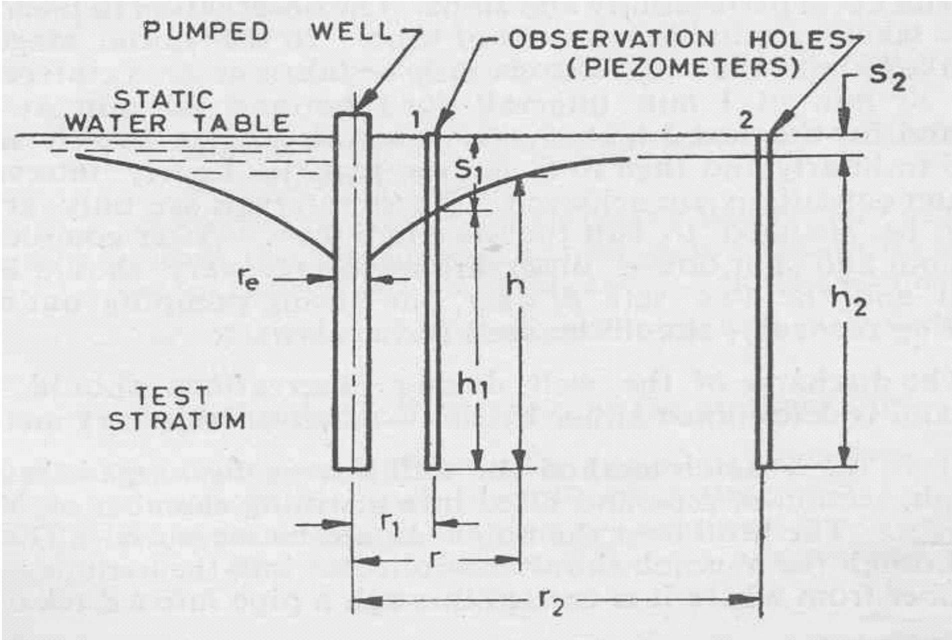



FIG. 10 TYPICAL ARRANGEMENT FOR PUMPING OUT TEST

of pumping out and shut down, observations for recovery should be also continued and the two sets of data, one during pumping out and the other during recovery, should be used for analysis.

**4.3.4** The discharge of the well during observations should remain constant and is determined either by the V-notch or trajectory method.

**4.3.4.1** In the V-notch method the well flow is discharged through a 5 m straight section of pipe and fitted into a stilling chamber of V-notch arrangement. The head over the notch should be measured. The water passing through the V-notch should be collected into the masonry collection chamber from where it is carried through a pipe into a ditch or drain lined with polythene plastic to prevent water from seeping into the sand aquifer in the vicinity of the well. The ditch is sited at least 150 m downstream of the V-notch. For a 90° V-notch, discharge = 2.56 $H^{5/2}$ where $H$ is the head of water over the notch.

**4.3.4.2** *Trajectory method*

The water emerging from a pipe flowing full will follow the ideal parabolic curve for a considerable distance; hence the equation of a free jet may be used for estimating the velocity at which water leaves the pipe by measuring the jet coordinates. If the outlet pipe is horizontal and referring to the mid-point of the outlet as the origin, then the velocity at any point on the jet is given by $V_0 = X\sqrt{g/2(Z)}$ in which $X$ and $Z$ are the horizontal and vertical coordinates of the point. Since the pipe from which water is coming out is full of water, the velocity multiplied by its cross-sectional area gives the discharge for the pipe.

**4.3.5** *Adjustment for Partial Penetration*

**4.3.5.1** The formulae for the computation of coefficient of transmissivity as mentioned in **4.5.1.1** and **4.5.1.2** are applicable only for fully penetrating wells. If the well is partially penetrating then the adjustment for the partial penetration of the aquifer is done. Kozeny modified this theoretical formula for partial penetration of wells. According to Kozeny, for equal values of drawdown, if vertical permeability is equal to horizontal permeability the relation between the values of discharge in partially and fully penetrating wells is given as below:

$$Q_p = Q_f \alpha \left\{ 1 + 7(\sqrt{\frac{r_e}{2\alpha b}} \cos\frac{\alpha\pi}{2} \right\} \qquad \dots (5)$$

where

$Q_p$ = constant rate of discharge for partially penetrating well in l/min;

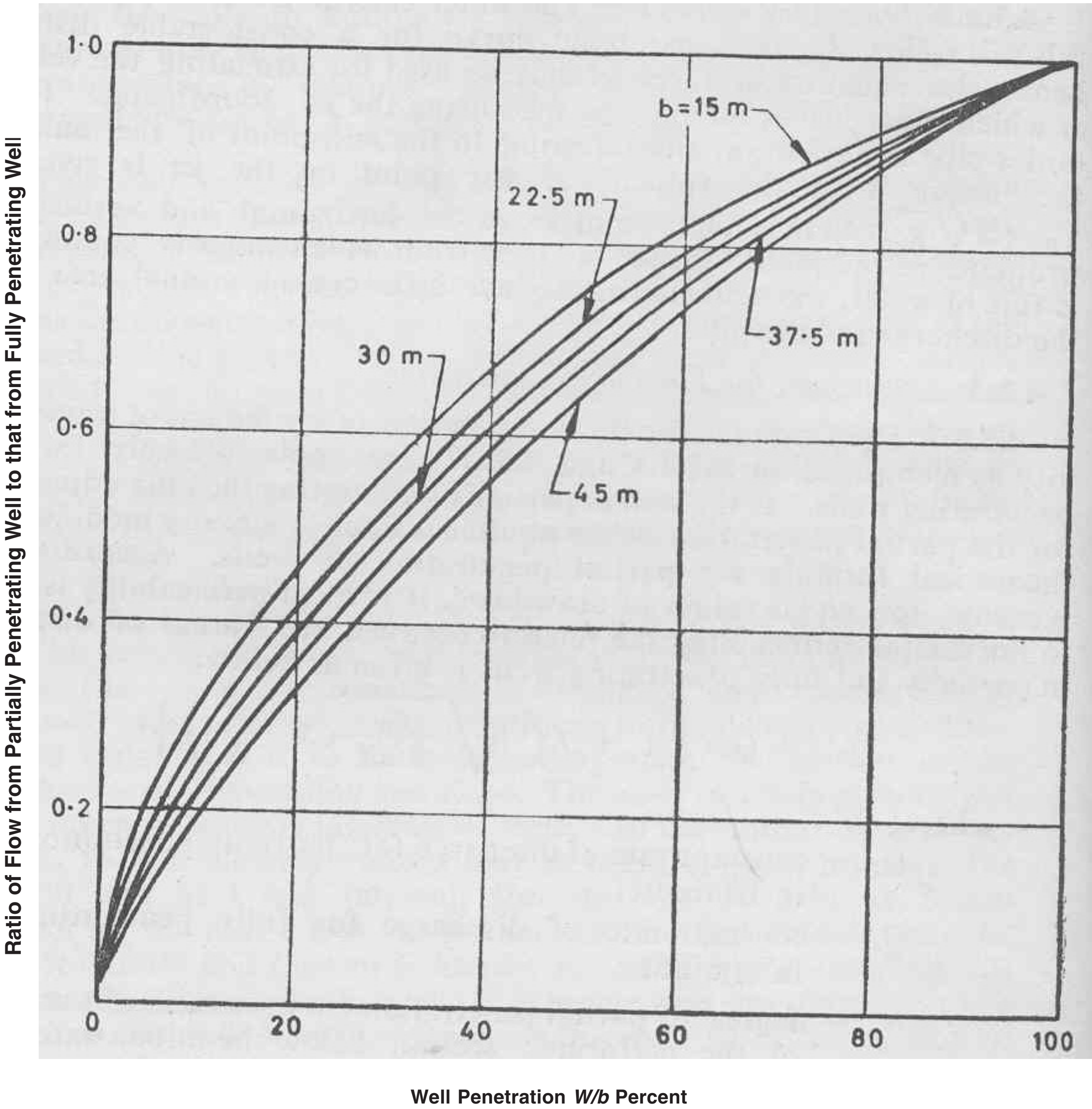
$Q_f$ = constant rate of discharge for fully penetrating well in 1/min;

$\alpha$ = degree of partial penetration (that is ratio of the length of the perforated section below the initial water table to the full saturated thickness of the unconfined aquifer);

$r_e$ = effective radius of the pumping well, in m (*see* Fig. 10); and

$b$ = full saturated thickness of the aquifer, in m.

**4.3.5.2** The discharge $Q_p$ observed in partially penetrating well should be corrected to the discharge $Q_f$ for fully penetrating well by the above relation and the same should be used for computation of coefficient of transmissivity $T$. Graphical solution of Kozeny's expression is given in Fig. 11 for ease in calculation. It may also be mentioned that the average drawdown in partially penetrating wells observed in observation wells located at a distance greater than 1.5 times the thickness of the aquifer is not effected by partial penetration, and analysis may be performed as for fully penetrating wells.




NOTE — Curves are for $r_e$=0.3 m and $R$ = 300 m.

$W$ = depth of penetration of well; and

$b$ = full saturated thickness of the aquifer.

FIG. 11 RELATION BETWEEN FLOW FROM A PARTIALLY PENETRATING

**4.4 Observations**

The observations of the test should be recorded suitably. A recommended proforma for the record of results is given in Annex D.

**4.5 Computation of Coefficient of Transmissivity**

The coefficient of transmissivity *T* is determined either by the Theis unsteady state or non-equilibrium method or by Theim's steady state formula.

**4.5.1** The unsteady state of non-equilibrium method is applicable for confined aquifer only and for fully penetrating wells. For unconfined aquifer, correction as detailed in **4.5.4** may be carried out in the value of drawdown *s* in an observation well and the same formula as for confined case may be used.

**4.5.1.1** The drawdown in an observation well in the unsteady state is given by Theis's well formula:

$$s = \frac{Q_t}{4^{\pi} T} \int_{u}^{\alpha} \frac{e^{-u}}{u} du \qquad \text{...(6)}$$

where

- $s$ = drawdown in observation hole,
- $Q_t$ = constant rate of discharge for fully penetrating well,
- $e$ = base of natural logarithms = 2.718,
- $T$ = coefficient of transmissivity,
- $u$ = $\frac{r^2 S}{4Tt}$,
- $r$ = distance of observation well from pumped well,
- $S$ = coefficient of storage, and
- $t$ = time since pumping started.

Expressing $Q_t$ in 1/min and $T$ in l/day/m:

$$s = \frac{114.6\, Q_t}{T} \int_{u}^{\pm} \frac{e^{-u}}{u} du \qquad \text{....(7)}$$

where

- $s$ = drawdown in the observation hole, in m;
- $u$ = $250\, r^2 S/Tt$;
- $t$ = time since pumping started in days;
- $r$ = distance of observation well from pumped well, in m;
- $S$ = coefficient of storage; and
- $T$ = coefficient of transmissivity in l/day/m.

**4.5.1.2** The integral of equation (7) is a function of the lower limit and is written as *W* (*u*), which is called well function of *u*. It can be expanded in convergent series given by:

$$W(u) = -0.577\,2 - \log_e u + u - \frac{u^2}{3 \times 2!} + \frac{u^2}{3 \times 3!} \qquad \text{... (8)}$$

**4.5.1.3** Solution of the integral of equation (7) for *T*, however, is relatively difficult since it occurs both inside and outside the integral function. A graphical method of superimposition devised by Theis makes it possible to obtain a simple solution of equation (7). Substituting the value of *W* (*u*) for the integral, equation (7) becomes:

$$S = \frac{114.6}{T} Q_f \left[ -0.5772 - \log_e \frac{250 r^2 S}{Tt} \cdot + \frac{250\, r^2 S}{Tt} - \frac{\left(\frac{250\, r^2 S}{Tt}\right)^2}{2 \times 2!} + \frac{\left(\frac{250\, r^2 S}{Tt}\right)^3}{3 \times 3!} \right]$$

If in a test $R_f$, *S* and *T* are constant, the equations: (8) and (9) indicate that *s* is related to $r^2/t$ in a manner that is similar to the relation of *W (u)* to *u*. Consequently, if values of drawdown *s* are plotted against $r^2/t$ on a logarithmic paper to the same scale as *W* (*u*) *versus u*, called the type curve, the curve of the observed field data will be similar to the type curve. The plot of *W* (*u*) *versus u* (*see* Fig. 12) is simply a graphical solution of equation (8) and is plotted for reference. The values of *W*(*u*) for values of *u* from $10^{-15}$ to 9.0 (as tabulated by Wenzel) are given in Table 2.

**4.5.1.4** The graphical solution for *T* is as follows:

a) Plot the type curve *W* (*u*) *versus u*, using log paper as shown by continuous line in Fig. 12. The values of *W* (*u*) are taken from Table 2.
b) Plot the field data *s versus* $r^2/t$ using log paper to the same scale as the type curve, shown by circles in Fig. 12. (Either the type curve or the field curve should be on transparent paper for convenience in superimposing.)
c) Superimpose the two curves (transparent curve is kept at the top) shifting laterally and vertically but keeping the scale parallel to a position which represents the best fit of the field data to the type curve.
d) With both graph sheets at the best match position, select an arbitrary point on the top curve and mark on the lower curve.

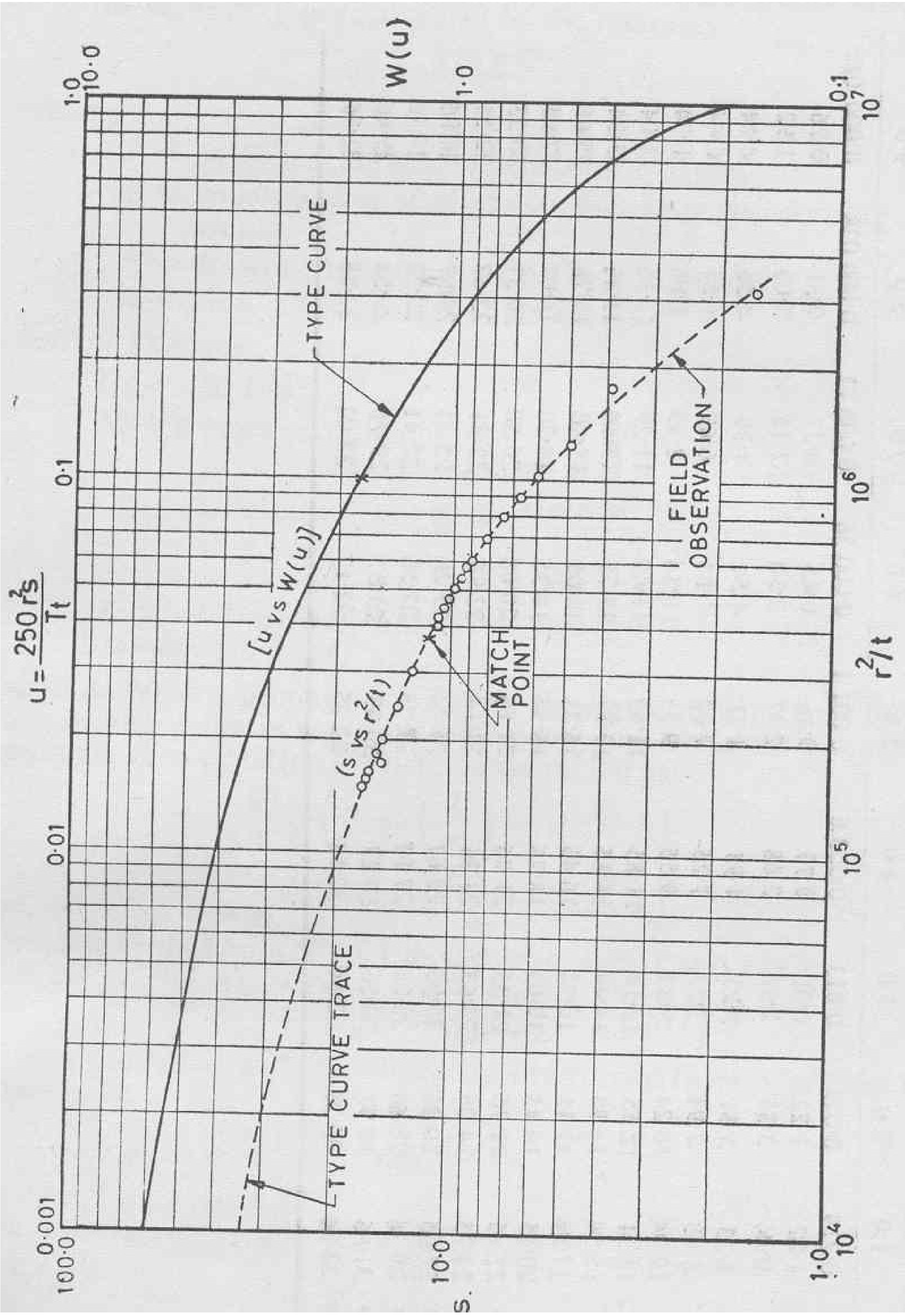



FIG. 12 LOGARITHMIC GRAPH OF THE EXPONENTIAL INTEGRAL TYPE CURVE

**Table 2 Values of *W (u)* for Values of *u***
(*Clauses* 4.5.1.3 *and* 4.5.1.4)

| Sl No. (1) | *u* (2) | **1.0** (3) | **2.0** (4) | **3.0** (5) | **4.0** (6) | **5.0** (7) | **6.0** (8) | **7.0** (9) | **8.0** (10) | **9.0** (11) |
|---|---|---|---|---|---|---|---|---|---|---|
| i) | ×1 | 0.219 | 0.049 | 0.013 | 0.003 8 | 0.001 1 | 0.000 36 | 0.000 12 | 0.000 038 | 0.000 012 |
| ii) | $\times10^{-1}$ | 1.82 | 1.22 | 0.91 | 0.70 | 0.56 | 0.45 | 0.37 | 0.31 | 0.26 |
| iii) | $\times10^{-2}$ | 0.04 | 3.35 | 2.96 | 2.68 | 2.47 | 2.30 | 2.15 | 2.03 | 1.92 |
| iv) | $\times10^{-3}$ | 6.33 | 5.64 | 5.23 | 4.95 | 4.73 | 4.54 | 4.39 | 4.26 | 4.14 |
| v) | $\times10^{-4}$ | 8.63 | 7.94 | 7.53 | 7.25 | 7.02 | 6.84 | 6.69 | 6.55 | 6.44 |
| vi) | $\times10^{-5}$ | 10.94 | 10.24 | 9.84 | 9.55 | 9.33 | 9.14 | 8.99 | 8.86 | 8.74 |
| vii) | $\times10^{-6}$ | 13.24 | 12.55 | 12.14 | 11.85 | 11.63 | 11.45 | 11.29 | 11.16 | 11.04 |
| viii) | $\times10^{-7}$ | 15.54 | 14.85 | 14.44 | 14.15 | 13.93 | 13.75 | 13.60 | 13.46 | 13.34 |
| ix) | $\times10^{-8}$ | 17.84 | 17.15 | 16.74 | 16.46 | 16.23 | 16.05 | 15.90 | 15.76 | 15.65 |
| x) | $\times10^{-9}$ | 20.15 | 19.45 | 19.05 | 18.76 | 18.54 | 18.35 | 18.20 | 18.07 | 17.95 |
| xi) | $\times10^{-10}$ | 22.45 | 21.76 | 21.35 | 21.06 | 21.84 | 20.66 | 20.50 | 20.37 | 20.25 |
| xii) | $\times10^{-11}$ | 24.75 | 24.06 | 23.65 | 23.36 | 23.14 | 22.96 | 22.81 | 22.67 | 22.55 |
| xiii) | $\times10^{-12}$ | 27.05 | 20.36 | 25.96 | 25.67 | 25.44 | 25.26 | 25.11 | 24.97 | 24.86 |
| xiv) | $\times10^{-13}$ | 29.36 | 28.66 | 28.26 | 27.97 | 27.45 | 27.56 | 27.41 | 27.28 | 27.16 |
| xv) | $\times10^{-14}$ | 31.66 | 30.97 | 30.56 | 30.27 | 30.05 | 29.87 | 29.71 | 29.58 | 29.46 |
| xvi) | $\times10^{-15}$ | 33.96 | 33.27 | 32.86 | 32.58 | 32.35 | 32.17 | 32.02 | 31.88 | 31.76 |

e) Knowing the value of $W(u)$ from the match point coordinate the value of $T$ is determined by the relation:

$$T = \frac{114.6\ Q_t}{s} W(u)$$

where

$T$ = coefficient of transmissivity, in l/day/m;

$Q_f$ = constant rate of discharge for fully penetrating well, in 1/min;

$s$ = drawdown in observation hole, in m; and $W(u)$ is a function defined in **4.5.1.2**.

*Numerical Example*

$Q_f$ = 250 1/min

Match point coordinates:

$u$ = 0.1, $W(u) = 1.82$

$r^2/t$ = $3.75 \times 10^5$, $s = 11.6$ m

$$T = \frac{114.6\ Q_f}{s} \times W(u) = \frac{114.6 \times 250 \times 1.82}{11.6}$$

$$= 4\ 500\ 1/\text{day/m}$$

**4.5.2** *Modified Unsteady State of Non-equilibrium Formula (Time Drawdown Method)*

**4.5.2.1** When $u$ becomes small after the lapse of sufficient time, the terms in the series of equation (8) beyond $\log_e u$ are not of appreciable magnitude, then equation (6) may be simplified as:

$$s = \frac{Q_f}{4\ \pi\ T}\left(\log e\left(\frac{1}{u}\right) - 0.577\ 2\right) \quad .... (10)$$

$$= \frac{Q_f}{4\ \pi\ T}\left(\log_e \frac{4T\ t}{r^2\ S} - 0.577\ 2\right)$$

Expressing $Q_f$ in 1/min, $T$ in 1/day/m, $t$ in days, $r$ and $s$ in m:

$$s = \frac{114.6\ Q_f}{T}\left(\log_e \frac{T\ t}{250\ r^2 S} - 0.577\ 2\right) \quad .... (11)$$

For one particular well, the change in drawdown from $s_1$ at time $t_1$ to $s_2$ at time $t_2$ is :

$$s_2 - s_1 = \frac{114.6\ Q_f}{T} \log_e \frac{t_2 r_1^2}{t_1 r_2^2} \quad ....(12)$$

$$\text{or } s_2 - s_1 = \frac{264\ Q_f}{T}\left(t_2 r_1^2 / t_1\ r_2^2\right)$$

where

$s$ = drawdown in observation hole, in m;

$Q_f$ = constant rate of discharge for fully penetrating well, in 1/min;

$$u = \frac{r^2\ S}{4.T\ t}$$

$r$ = distance of observation hole from pumped well, in m;

$S$ = coefficient of storage;

$T$ = coefficient to transmissivity, in 1/day/m;

$t$ = time since pumping started, in days;

$s_1$ = drawdown at time $t_1$ from start of pumping, in m;

$s_2$ = drawdown at time $t_2$ from start of pumping, in m; and

$r_1$, $r_2$ = distance of observation holes 1 and 2 from pumped well, in m.

The most convenient procedure for application of the above equation is to plot the observational data for each

well on semi log coordinate paper as shown in Fig. 13. From this curve make an arbitrary choice of $r_1^2/t_1$ and $r_2^2/t_2$ and note the corresponding values of $s_1$ and $s_2$. For convenience $r_1^2/t_1$ and $r_2^2/t_2$ and are chosen one log-cycle, apart, and then

$$\log_{10}\left(r_1^2 t_2 / r_2^2 t_1\right) = 1$$

$$\text{or} \quad s_2 - s_1 = \Delta s = \frac{264\,Q_f}{T}$$

$$\text{or} \quad T = \frac{264\,Q_f}{\Delta s}$$

where

$s$ = drawdown difference per log cycle, in m.

*Numerical Example*

$Q_f$ = 250 1/min

$r$ = 48 m

$$T = \frac{264\,Q_f\,\log_{10}\left(t_2/t_1\right)}{s_2 - s_1}$$

$$\text{or} \quad T = \frac{264 \times 250 \times \log_{10}(100/10)}{26.8 - 12.2}$$

or $T$ = 4 520 1/day/m

**4.5.3** *Analysis by Recovery Data*

**4.5.3.1** If a well that has been pumping for definite period of time at a constant rate is shut down then recovery of the water table takes place. The head distribution thereafter is obtained by superimposing a recharge well of the same strength as the discharge well, upon the discharge well, to bring the net discharge to zero. The residual drawdown $s'$ (that is the difference at any time between the static level and the recovering water level) is the algebraic sum of the drawdown resulting from the start-up and the recovery resulting from the shutdown (assuming no leakage around the casing and neglecting the volume of water that momentarily flows back into the well from the pump column).

Thus

$$s' = \frac{2.30\,Q_f}{4\,\pi\,T}\left(\log\frac{2.25\,T\,t}{r^2 S} - \log\frac{2.25\,T\,t'}{r^2\,S}\right)$$

$$s' = \frac{2.30\,Q_f}{4\,p\,T}\log t/t' \qquad \ldots(13)$$

where

$s'$ = residual drawdown,

$Q_f$ = constant rate of discharge for fully penetrating well,

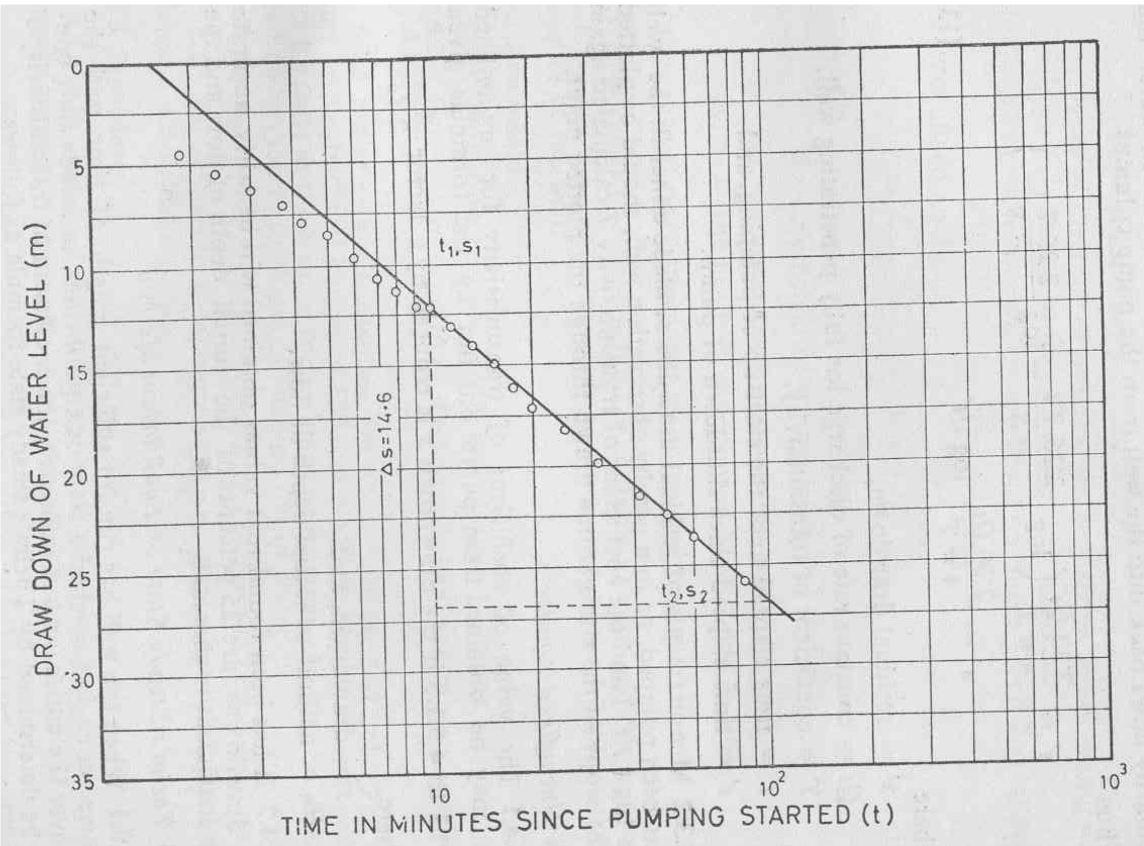



FIG. 13 SEMI-LOG GRAPH OF PUMPING TEST DATA FOR APPLICATION OF MODIFIED THEIS FORMULA

$T$ = coefficient of transmissivity,

$T$ = time elapsed since the start-up of pumping, and

$t'$ = time elapsed since shutdown of pump.

**4.5.3.2** Measurements of residual drawdown, made either in the well that has been pumped, or in a nearby observation well, should be plotted against log ($t/t'$) and the coefficient of transmissivity $T$ calculated again from the slope of the straight line drawn through the plotted point.

**4.5.4** *Unconfined Aquifer*

**4.5.4.1** The value of coefficient of transmissivity for unconfined aquifer may be obtained from pump out test by the formulae given in **4.5.1.1** to **4.5.1.3**, if the drawdown $s$ is reduced by a factor

$$\frac{s}{2H_0}$$

where

$s$ = drawdown, and

$H_0$ = natural or initial depth of flow.

**4.5.4.2** It has been found that values obtained will be fairly accurate, if the drawdowns are 25 percent of the initial depth of flow and the storage coefficient is constant.

**4.5.5** *Theim's Steady State or Equilibrium Method*

**4.5.5.1** When the well has run for sufficient length of time and the drawdown cone has reached a state or equilibrium, or steady flow condition over the entire area of influence, the coefficient of transmissivity $T$ should be determined by Theim's steady state formula as follows:

$$T = \frac{Q_f}{2\pi(s_1 - s_2)} \log_e \frac{r_2}{r_1} \qquad \text{.... (14)}$$

where

$T$ = coefficient of transmissivity;

$Q_f$ = constant rate of discharge;

$r_1$, $r_2$ = distance of observation holes from the pumping well as shown in Fig. 10; and

$s_1$, $s_2$ = drawdown in observation holes 1 and 2 as shown in Fig. 10.

For unconfined aquifer:

$$T = \frac{Q_f}{\left(h_2^{\,2} - h_1^{\,2}\right)} \log_e r_2 / r_1 \qquad \text{... (15)}$$

where

$T$ = coefficient of transmissivity;

$Q_f$ = constant rate of discharge; and

$h_1$, $h_2$ = heads in observation holes 1 and 2.

## 5 PUMPING OUT TEST BY BAILOR METHOD

### 5.1 Applicability

The method is applicable to the approximate determination of the permeability of the strata up to shallow depth in the close vicinity of the well.

### 5.2 Equipment

**5.2.1** *Boring Set* — One, of 200 mm to 250 mm.

**5.2.2** *Casing Pipe* — To fit in the above hole with strainer attached as in **4.2.4**.

**5.2.3** *Bailor* — One for bailing out water from the test hole. The bailor may be a cylindrical bucket of 150 mm dia and 0.3 m long attached with a 7 kg mass at the bottom for sinking the bailor in the water. A rope is tied on the top to facilitate the bailing out of water.

**5.2.4** *Equipment for Measuring Water Level in the Test Hole*

**5.2.5** *Miscellaneous Equipment* — Tape, stop watch, graduated cylinder and enamelled buckets.

### 5.3 Procedure

**5.3.1** The boring of the hole, sinking the casing and cleaning the hole should be done by the method described in **3.2.3.1**.

**5.3.2** The water from the well should be bailed out for the first bailor cycle and the time at which the water is bailed out should be noted. The water level in the well should be allowed to recover and the recovery after arbitrary time $t$ should be noted in the well itself. The residual drawdown (static water level – recouped water level) should also be noted. The process should be repeated for a number of bailor cycles and the final residual drawdown should be determined.

### 5.4 Computation of Coefficient of Transmissivity

**5.4.1** When bailing of a well is stopped then at any point on the recovery curve, the following equation applies:

$$s' = \frac{V}{4\pi T t\left(e^{-(r_w)^2} .\, S/4Tt\right)} \qquad \text{.... (16)}$$

where

$s'$ = residual drawdown;

$V$ = volume of water removed in one bailor cycle;

$T$ = coefficient of transmissivity;

$t$ = length of time since the bailor was removed;

$r_w$ = effective radius of the well; and

$S$ = coefficient of storage.

**5.4.1.1** The effective radius $r_w$ of the well is very small in comparison to the extent of the aquifer. As $r_w$ is small the exponential term in equation (16) approaches to unity as $t$ becomes larger. Therefore, for large values of $t$, the equation becomes (symbols same as in **5.4.1**):

$$s' = \frac{V}{4\pi Tt} = \frac{V}{12.57\,Tt}$$

**5.4.1.2** If the residual drawdown is observed at some time after completion of $n$ bailor cycles, then the following expression applies:

$$s' = \frac{1}{12.57\,T}\left(\frac{V_1}{t_1} + \frac{V_2}{t_2} + \frac{V_3}{t_3} + ... + \frac{V_n}{t_n}\right)$$

where, the subscripts merely identify each cycle of events in sequence. Thus, $V_3$ represents the volume of water removed during the third bailor cycle and $t_3$ is the elapsed time from the instant that water was removed from storage to the instant at which the observation of residual drawdown was made.

**5.4.1.3** If approximately the same volume of water $V$ is removed by the bailor during each cycle the equation becomes:

$$s' = \frac{1}{12.57\,T}\left(\frac{1}{t_1} + \frac{1}{t_2} + \frac{1}{t_3} + ... + \frac{1}{t_n}\right)$$

or $$T = \frac{V}{12.57s'}\sum_{n=1}^{n=n}\frac{1}{t_n}$$

where

$n$ = number of bailing cycles.

**5.4.1.4** Expressing $V$ in litre, $t$ in days, $s'$ in m, then $T$ is expressed in 1/day/m.

**5.4.2** The bailor method is applied to a single observation of the residual drawdown after the time since bailing stopped, becomes large. The transmissivity is computed by substituting in equation, the observed residual drawdown, the volume of water $V$ considered to be the average quantity removed by the bailor in each cycle, and the summation of the reciprocal of the elapsed time, in days, between the time each bailor of water removed from the well and time of observation of residual drawdown.

**5.5 Observations**

The observations of the test should be recorded suitably. A recommended proforma for the record of results is given in Annex E.

## 6 LIMITATIONS OF PUMPING OUT TESTS

**6.1** It is a very uneconomical and cumbersome method.

**6.2** It does not give correct value of permeability for stratified foundations.

**6.3** Correct value of permeability is obtained only when the well has been pumped for quite a long time and no sand is coming out of the pumped well.

## 7 COMPUTATION FOR COEFFICIENT OF PERMEABILITY

**7.1** The coefficient of permeability $K$ is computed from the values of the coefficient of transmissivity by the relation given below:

$$K = T/b$$

expressing $T$ in 1/day/m, $b$ in m and $K$ in m/day,

$$K = T/b \times 10^{-3}$$

where

$K$ = coefficient of permeability in m/day;

$T$ = coefficient of transmissivity in l/day/m; and

$b$ = aquifer thickness in m.

**7.2** The coefficient of permeability $K$ may be expressed in cm/s by the relation given below:

$$1 \text{ m/day} = 1.157 \times 10^{-3} \text{ cm/s}$$

## ANNEX A
(*Clause* 3.2.4)

### PROFORMA FOR RECORD OF OBSERVATIONS OF TEST BY CONSTANT HEAD METHOD

1) Test No.:

2) Test location:

a) Elevation of ground:
b) Elevation of ground water table:
c) Elevation of the test section:
d) Diameter of test hole:

| *Sl No.* | *Time* min | *Elevation of Water Level in the Casing* | *H for Test Below Water Table = Elevation of Water Level in the Casing – Elevation of Ground Water Table* | *H for Test Above Water Table = Elevation of Water Level in the Casing — Elevation of the Test Section* |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| i) | 5 | | | |
| ii) | 10 | | | |
| iii) | 15 | | | |
| iv) | 20 | | | |
| v) | 25 | | | |

**Table for Discharge**

| *Sl No.* | *Discharge in* | *Discharge* |
|---|---|---|
| i) | | |
| ii) | | |
| iii) | | |

## ANNEX B
(*Clause* 3.3.4)

### PROFORMA FOR RECORD OF OBSERVATIONS OF TEST BY FALLING HEAD METHOD

1) Test location:
2) Test No.:
3) Elevation of the ground:
4) Elevation of the ground water table:
5) Diameter of the intake pipe *(d)*:
6) Length of the test section (*L*):
7) Water level at time $t_0$ ($h_0$):

| *Sl No.* | *Time,* min | *Water Level in the Intake Pipe* | *Height of Water Level at Time t, $H_{-t}$ = Water Level in the Intake Pipe-Elevation of the Ground Water Table* |
|---|---|---|---|
| (1) | (2) | (3) | (4) |
| i) | 0 | | |
| ii) | $\frac{1}{2}$ | | |
| iii) | 1 | | |
| iv) | 2 | | |
| v) | 5 | | |
| vi) | 10 | | |
| vii) | 15 | | |
| viii) | 30 | | |
| ix) | 60 | | |

NOTE — Observations should be stopped when water level in the intake pipe recedes to ground water table (or earlier).

## ANNEX C
(*Clause* 3.4.5)

### PROFORMA FOR RECORD OF OBSERVATIONS OF TEST BY SLUG METHOD

Before Starting Injection

| *Sl No.* | *Time* min | *Existing Water Level* |
|---|---|---|
| i) | 0 | |
| ii) | 2 | |
| iii) | 5 | |

Average ($H_1$) =

Time at which injection started ($t_1$) =

Time at which injection stopped ($t_2$) =

$$Average = \frac{t_1 + t_2}{2} =$$

| *Sl No.* | *Time Recorded After [($t_1$+$t_2$)/2],* min, $t_m$ | $1/t_m$ | *Water Level* $H_2$ | *Residual Head* = $s = (H_2 - H_1)$ |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| i) | 0 | | | |
| ii) | 1 | | | |
| iii) | 2 | | | |
| iv) | 5 | | | |
| v) | 10 | | | |
| vi) | 15 | | | |

# ANNEX D
(*Clause* 4.4)

## PROFORMA FOR RECORD OF OBSERVATIONS OF PUMPING OUT TESTS

Date:

1) Test location:
2) Test hole No.:
   a) Diameter of the well:
   b) Level of water table:
   c) Thickness of saturated strata below water table:
   d) Penetration of the well:
   e) Length of strainer the well:
   f) Length of top blind pipe of the well:
   g) Length of strata tested (RL to RL):
   h) Ground level:

### DRAWDOWN OBSERVATIONS

| *Sl No.* | *Time* | *Line No.* | Piezometer No. (As per plan) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | *Well* | 1 | 2 | 3 | 4 | 5 | 6 |
| i) | | 1 | | | | | | | |
| ii) | | 2 | | | | | | | |
| iii) | | 3 | | | | | | | |

### DISCHARGE OBSERVATIONS

(A) By Trajectory Method

| *Sl No.* | *X* | *Y* | *V* | *Amount of Seepage* m1/min | $Q_f$ m1/min |
|---|---|---|---|---|---|

(B) V-Notch Method

| *Sl No.* | *Head of Water Over Notch* | *Discharge* $Q_f$ ml/min |
|---|---|---|

## ANNEX E
(*Clause* 5.5)

### PROFORMA FOR RECORD OF OBSERVATIONS OF PUMPING OUT TEST BY BAILOR METHOD

1) Test location: Date:
2) Test hole No.:
   a) Diameter of wells:
   b) Level of water table:
   c) Thickness of saturated strata between water table:
   d) Penetration of well:
   e) Length of strainer of the well:
   f) Length of top blind pipe of the well:
   g) Length of strata tested (RL to RL):
   h) Ground level:
   j) Residual drawdown after *n* bailor cycles:

### OBSERVATIONS OF RECOVERY

| *Sl No.* | *Volume of Water Bailed Out* | *Time Since Bailor Removed,* min | *Final Time After Completion of the Cycle,* min | *t = Final Time After Completion of the Cycle – Time Since Bailor Removed,* min | *Remarks* |
|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1st cycle | | | | | |
| 2nd cycle | | | | | |
| 3rd cycle | | | | | |
| 4th cycle | | | | | |

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